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ABSTRACT

The purpose of this research was to analyze recent statistics textbooks in the behavioral sciences in terms of their coverage of exploratory data analysis (EDA) philosophy and techniques. Twenty popular texts were analyzed. EDA philosophy was not addressed in the vast majority of texts. Only three texts had an entire chapter on EDA. None of the authors used the term "confirmatory factor analysis" or discussed model building or cross-validation. Seven texts contained references to published work by Tukey, but these references were mainly for specific techniques, most typically the stem-and-leaf display and box-and-whiskers plot, which were presented in 15 and 9 texts respectively. The paper ends with recommendations for integrating EDA into the fields of psychology and education. (Contains 1 table and 35 references.) (Author/SLD)

Whatever Happened to Exploratory Data Analysis?

An Evaluation of Behavioral Science Statistics Textbooks

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Abstract

The purpose of this research was to analyze recent statistics textbooks in the behavioral sciences in terms of their coverage of exploratory data analysis (EDA) philosophy and techniques. Twenty popular texts were analyzed. EDA philosophy was not addressed in the vast majority of texts. Only three texts had an entire chapter on EDA. None of the authors used the term "confirmatory data analysis" or discussed model building or cross-validation. Seven texts contained references to published work by Tukey, but these references were mainly for specific techniques, most typically the stem-and-leaf display and box-and-whiskers plot, which were presented in 15 and 9 texts, respectively. The paper ends with recommendations for integrating EDA into the fields of psychology and education.

Whatever Happened to Exploratory Data Analysis? An Analysis of Behavioral Science Statistics Textbooks

The vast majority of research conducted in the behavioral sciences is based on a confirmatory data analysis (CDA) model. In CDA, the researcher states a null and alternative hypothesis, designs a study, collects data, analyzes the data using one or more statistical significance test, and then makes a decision about whether or not to reject the null hypothesis. To help interpret the research results, the researcher usually considers summary statistics such as means, standard deviations, and effect size indices. He or she might also consider confidence interval estimates, although this occurs less frequently, and might also generate summary graphs such as bar charts and histograms.

Since the early 1960s, John Tukey and his colleagues have written about the limitations associated with carrying out CDA without first conducting exploratory data analysis (EDA). Tukey and his colleagues have argued that by relying solely on CDA, too much trust is placed on statistical summaries of the data, which may, in fact, hide or misrepresent important aspects the data. The Anglo Saxon jurisprudence model has often been used as a metaphor for describing the differences between CDA and EDA. EDA has been likened to the investigative aspects of a legal case (i.e. the "detective work"), whereas CDA has been likened to a jury trial, where the goal is to make a decision about guilt or innocence. (See Hoaglin, Mosteller, and Tukey, 1983; Mosteller and Tukey 1977; Tukey, 1977).

In 1977, Tukey published his classic textbook entitled *Exploratory Data Analysis*. In this textbook and in other writings, Tukey described EDA as *attitude* towards data analysis in which the researcher is *skeptical* of statistical summaries and *open* to finding patterns in the data that might not have been anticipated. Tukey described EDA as an iterative model-building process

that involves examining data from multiple perspectives; developing tentative hypotheses; re-analyzing the data with these tentative hypotheses in mind; revising hypotheses; and so forth. Ultimately, the exploratory data analyst is looking for a model that will explain the data. This tentative model can then be cross-validated with a second sample using CDA techniques. Tukey and his colleagues have argued that CDA should *always* be preceded by EDA. As Tukey stated, "exploratory data analysis can never be the whole story, but nothing else can serve as the foundation stone—as the first step" (Tukey, 1997, p. 3).

Tukey developed a number of techniques for carrying out EDA. He was a strong advocate of analyzing graphical displays, especially those that include information on individual data points, and he developed the stem-and-leaf display and box-and-whiskers plot to this end. Tukey was also a strong advocate of examining "resistant indicators"--a term he coined--which are statistical summaries that are less impacted by extremes in the data (such as the median and inter-quartile range).

It has been over 25 years since *Exploratory Data Analysis* was published (Tukey, 1977). Since that time, a number of leading methodologists and statisticians in the behavioral sciences have been strong advocates of integrating EDA into the behavioral science research process (see, for example, Behrens, 1997; Cohen, 1990, 1994). For example, in his article on the use of EDA in the field of psychology, Behrens argued:

> EDA should be recognized as an important aspect of data analysis whose conduct and publication are valued. By admitting EDA as an acceptable set of procedures, researchers can avoid the improper use of CDA techniques for the purpose of data exploration. As long as EDA remains a covert activity, researchers will continue to improperly use CDA for data exploration through model underspecification and

overtesting. An increase in EDA will focus more resources at the preliminary stages of investigations and less at the advanced stages. In doing so, the number of irreproducible results may be reduced by the substitution of adequate model building for the cataloging of significant effects. Further, the detail in modeling afforded by EDA may improve our understanding of phenomenon otherwise hidden behind simple summary statistics and tests ... (p. 154)

What impact have Tukey and his colleagues had on the way in which data analysis is taught in the behavioral sciences? Exploratory data analysts would argue that EDA should always be a part of statistical training, not as a topic which is taught separately in advanced graduate-level courses, but as an integral component of any basic statistics course, including undergraduate courses. But to what extent is this actually occurring? For better or worse, the content of behavioral science statistics textbooks will determine the curriculum of most statistics classes. The purpose of this study was therefore to conduct a content analysis of current statistics textbooks in the behavioral sciences to evaluate the extent to which EDA philosophy, general heuristics, and specific techniques are covered in these textbooks.

Background

Exploratory Data Analysis

A detailed description of EDA is beyond the scope of this paper. The interested reader is referred to Tukey (1977), Mosteller and Tukey (1977), and Hoaglin, Mosteller, and Tukey (1983, 1985) for more thorough coverage. Excellent summaries of EDA can be found in Behrens (1997), Hartwig and Dearing (1979), and Leinhardt and Leinhardt (1980).

As mentioned, Tukey and his colleagues often compared the data analysis process to a jurisprudence model. As Behrens (1997) stated:

in EDA, the goal is not to draw conclusions regarding guilt or innocence but rather to investigate the actors, generate hunches, and provide preliminary evidence. EDA is more like an interrogation in which clean and corrupted stories are told, whereas CDA is testimony regarding evidence that fits carefully laid-out trial procedures. The goal of EDA is indictment; the goal of CDA is conviction. (p. 133)

EDA typically begins by examining each variable individually, combing through the data, checking the shapes of distributions, looking for outliers and rogue values. Then the exploratory data analyst turns to looking at relationships between pairs of variables, and finally considers multivariate relationships. Tukey (1977) developed a number of techniques to aid in EDA, but he repeatedly emphasized that the use of these techniques alone does not constitute EDA. Instead he argued that EDA is an *attitude*, and the techniques are simply tools.

Resistant indicators. Tukey was an advocate of using what he termed "resistant indicators" in data analysis. He coined the term the "five-number summary" of a distribution—namely the minimum value, first quartile (Q_1), median, third quartile (Q_3), and maximum value. (Actually, Tukey proposed statistics that he called "hinges", which are usually but not always equal to Q_1 and Q_3). Tukey discussed a variety of resistant indicators in addition to the five-number summary, but their presentation is beyond the scope of this article.

Graphical displays for univariate analyses. Tukey (1977) developed a number of graphical displays for EDA, but is probably best known for the stem-and-leaf plot and the box-and-whiskers plot. Stem-and-leaf displays are similar to histograms, except that they display each individual data point, and are useful for examining the shape of a distribution as well as for looking for rogue values. Box-and-whiskers plots, also known as box plots, do not display each individual data point, but instead display the five-number summary as well as "outside values".

Outside values. Tukey termed the difference between the hinges "H-spread", which is usually, but not always, equivalent to the inter-quartile range. He proposed a rule of thumb for identifying "outside" values based on this spread. In particular, Tukey proposed calculating 1.5 times the H-spread. Outside values are those values that are either (a) below the lower hinge minus 1.5 times the H-spread, or (b) above the upper hinge plus 1.5 times H-spread. These outside values are individually plotted in box plots.

Re-expression and smoothing. Tukey was also an advocate of what he called "re-expression" (i.e. monotonic nonlinear transformations) to the extent that the re-expression makes the data easier to understand (Tukey, 1977). These re-expressions include the log transformation, square root transformation, and reciprocal transformation. Tukey was also an advocate of applying smoothing techniques (i.e. kernel density smoothing), where some of the "rough" of the data is removed to get a better picture of a shape of a distribution (Tukey, 1977).

Examining bivariate relationships. Tukey proposed a variety of EDA techniques for examining the relationship between pairs of variables (Tukey, 1977). In terms of examining the relationship between two quantitative variables, Tukey advocated analyzing simple scatter diagrams, and proposed a technique for fitting a "resistant" line through the data points. (This line is sometimes referred to as a "Tukey line", and is an alternative to the ordinary least squares regression line). Tukey and his colleagues have written extensively on how to examine residuals in this context.

Studies on EDA in Behavioral Science Research

There are no empirical studies on the attitudes of researchers in the behavioral sciences towards EDA, or on the extent to which EDA is actually being used in behavioral science research. The only research that provides some insight into this issue is the research on the

statistics training of doctoral and undergraduate students in psychology. In terms of doctoral students, Aiken, West, Sechrest, and Reno (1990) found that 89% of the 186 departments they studied offered an introductory graduate statistics sequence, and of the departments offering this sequence, 77% were one year long. As mentioned, Aiken et al. found that 20% of introductory statistics sequence courses covered EDA in-depth. Furthermore, in only 15% of the departments were most or all doctoral students judged to be competent in modern graphical data display, and in only 8% of the departments were most or all doctoral students judged to be competent in the detection and treatment of influential data.

Friedrich, Buday, and Kerr (2000) conducted a similar study of undergraduate psychology majors. These researchers surveyed 185 “general” and 55 “elite” psychology programs, and found that a statistics course was required in 93% of the programs, either integrated with a research methods course (26%) or given as a stand-alone course (86%). Specific information on EDA training was not collected, but these researchers did find that in over half of the programs, one hour or less of introductory statistics class time was devoted to graphical analysis of data (e.g. box and whisker and residual plots).

Research on Evaluating Statistics Textbooks

There are many reviews of individual statistics textbooks. Journal such as *Journal of Educational and Behavioral Statistics* and *Journal of the American Statistical Association* routinely publish reviews of new and revised statistics textbooks. But there have been few systematic evaluations of statistics textbooks across one or more dimensions (Harwell, et. al., 1996), and only one that specifically considered EDA. Cobb (1987) evaluated 16 statistics textbooks on a variety of dimensions, including EDA. He distinguished between EDA techniques--such as stem-and–leaf diagrams and box-and-whiskers plots--and EDA attitudes--

which he described as attending to issues such as residuals, outliers, and transformations. Less than half of the books in his sample covered EDA attitudes. In terms of techniques, four texts had no coverage; four texts had one to four pages of coverage, and seven texts had more than four pages of coverage.

Unfortunately, it is difficult to draw inferences from Cobb's (1987) research to behavioral science research. First, the textbooks he evaluated were not written specifically for the behavioral sciences, but were instead general statistics textbooks. Second, his study is now 15 years old, so the findings might be dated.

Specific Research Interests

This study had three parts. First, the extent to which statistics textbook authors described the underlying philosophy and general heuristics of EDA was examined. Secondly, the extent to which statistics textbook authors presented data analytic tools commonly associated with EDA, including basic tools such as stem-and-leaf displays, dot charts, box-and-whiskers charts, and residual analysis, was studied. Finally, the extent to which the authors integrated EDA practices throughout their textbook was considered.

Methods

Sample. There were two main criteria for selecting textbooks. First, the textbook needed to be recent, which was defined as a publication date of 1998 or later. Second, the textbook needed to be written specifically for behavioral science audiences. There were 20 textbooks in the final sample. Fifteen of these textbooks were obtained based on information provided by the *Faculty Online* website (http://www.facultyonline.com). This site provides information on top selling textbooks, based upon sales information from university bookstores.

It seemed possible that a statistics textbook could be a top-seller because it is a "bare-

bones" text that is targeted towards a less-challenging statistics course, and that the sample textbooks might not include more rigorous introductory statistics textbooks. In order to be sure that more thorough texts were included, the publishers of the texts listed above were contacted and asked for their recommendations. Five more texts were added to the sample in this way.

The final sample consisted of 20 textbooks—15 from the *Faculty Online* website, namely Aron and Aron (1999); Frankfort-Nachmias and Leon-Guerrero (2000); Gravetter and Wallnau (2002); Healey (2002); Heiman (2000); Howell (2002); Hurlburt (1998); Jaccard and Becker (2002); Kiess (2002); Levin and Fox (2000); McCall (2001); Pagano (2001); Runyon, Coleman, and Pittenger (2000); Welkowitz, Ewen, and Cohen (2000); Witte and Witte (2001), and 5 recommended by sales representatives, namely Abrami, Cholmsky, and Gordon (2001); Bartz (1999); Hinkle, Wiersma, and Jurs (2001); Sprinthall (2000); and Thorndike and Dinnel (2001).

Results

Summary statistics of various EDA-related indicators are presented in Table 1.

Insert Table 1 about here.

EDA Philosophy

The underlying EDA philosophy was *not* addressed in the vast majority of textbooks. Only three textbooks contained an entire chapter devoted to EDA philosophy and techniques, and none of the remaining textbooks even had a major section devoted to EDA. Seven textbooks contained references to published work by Tukey and his colleagues, but in most of these textbooks, Tukey's work was cited as a reference for one or more specific *techniques*, rather than for an understanding EDA philosophy. And although all of the textbooks covered statistical significance testing in great detail, the term "confirmatory data analysis" was never used in any

textbook. Finally, the concept of cross-validation—which would be a critical issue in model-building with EDA--was not discussed in any textbook.

To get a rough indication of the extent to which EDA had been integrated throughout the textbooks, the sections of the textbooks that covered the matched-pair *t*-test or two-group *t*-test were analyzed in detail. Every illustration of one of these *t*-tests using actual data was coded in terms of whether or not the textbook author(s) first presented a graphical display of the data being analyzed. Thus, the question was simply whether the data were looked at prior to analysis. Only one textbook author presented an accompanying graphical display for these *t*-tests. As a further gauge of the extent to which EDA had been integrated, the end-of-chapter assignments that involved these *t*-tests were examined. Again, only one textbook required students to construct a graph prior to computing one of these *t*-tests. Thus, overall, there was virtually no integration of EDA principles across the chapters of these textbooks.

EDA Techniques

Graphical displays. For this analysis, the frequency of three basic EDA-related graphical displays was considered, namely Tukey's stem-and-leaf display, dot plot, and box-and-whiskers plot. The stem-and-leaf display and box-and-whiskers plot were presented in 15 and 9 texts, respectively, and in most of the textbooks that covered these displays, the authors attributed the origins of the stem-and-leaf display and box-and-whiskers plot to Tukey. In terms of using these displays to compare the distributions of two or more groups, the extension of the stem-and-leaf display was only shown in 8 of the 15 textbooks, whereas and box-and-whiskers plot for comparing groups was shown in 7 of the 9 textbooks. Tukey's dot plot was not presented in any of the textbooks.

Outside values and the box-and-whiskers plot. One useful aspect of the box-and-

whiskers plot is that individual data points for "outside" values can be plotted outside the bounds of the whiskers, as described earlier. In seven of the nine textbooks where the box-and-whiskers plot was presented, individual outside values were illustrated in the plots, although in one of these seven texts, the outside values were determined based on standard scores rather than Tukey's procedure. Of the remaining six textbooks that did use Tukey's procedure, the authors of two texts never explained how this was done. Thus, even though nearly half of the textbooks included box-and-whiskers plots, one of the most valuable aspects of this display was not explained most of textbooks.

Outliers. One of the hallmarks of EDA is paying attention to "unusual" values, which are sometimes called outliers, outside values, extreme scores, or rogue values. The extent to which textbook authors addressed the issue of outliers was also assessed, regardless of whether outliers were discussed in the context of EDA in the Tukey-tradition. Surprisingly, the topic of outliers in a single distribution was only mentioned in 12 textbooks, and in only 5 if these textbooks did the authors present one or more strategies for identifying these extreme values. (In 4 of the 5 texts, Tukey's procedure for identifying outside values was presented). The issue of how to actually *think* about outliers—in terms of their possible causes or in terms of how to handle them—was rarely discussed.

In order to get a rough sense of the extent to which the topic of outliers was addressed in more complex situations, the ways in which textbook authors addressed the possible effect of outliers on the Pearson Product moment correlation coefficient (r_{xy}) was also evaluated. This correlation coefficient was chosen because EDA emphasizes graphics, and because the underlying relationship between two quantitative variables can be easily inspected using a scatter diagram. The correlation coefficient was covered in all 20 textbooks. But in half of the texts,

the topic of the possible effects of one or more extreme scores on r_{xy} was not mentioned. And in most of the remaining textbooks, the issue of how to actually *think* about them—in terms of their possible causes or in terms of how to handle them—was again rarely discussed.

EDA-Influenced Statistics Textbooks

Textbooks with some EDA philosophy and a number of EDA techniques. There were five textbooks that were the "best of the lot" in terms of the way in which they covered EDA: Abrami, Cholmsky, and Gordon (2001); Hinkle, Wiersma, and Jurs (1998); Howell (2002); McCall (2001); and Runyon, Coleman, and Pittenger (2000). Three of these texts had entire chapters devoted to exploring data: (a) Howell; (b) McCall; and (c) Runyon, Coleman, and Pittenger). (Howell's chapter was entitled "Describing and Exploring Data", and wasn't strictly limited to describing EDA in the Tukey-tradition).

These five textbooks differed from the remaining texts not only in terms of the number of techniques covered, but also, more importantly, in terms of the *depth* of their coverage. All five textbooks included the stem-and-leaf display, and four of the five included presentations of back-to-back displays for comparing the distributions of two groups. Three of these texts were particularly notable in terms of how to use this display as a data analytic tool: Howell (2002); McCall (2001); and Runyon, Coleman, and Pittenger (2001). In all five of these textbooks, the authors also presented the box-and-whiskers plot, and in all five of these textbooks, outside values were included in the plots. (Abrami, Cholmsky, and Gordon (2001), however, didn't explain how these outside values were identified). Several of these texts were particularly detailed in terms of how to actually analyze data using these plots (see Abrami, Cholmsky, and Gordon 2001; Hinkle, Wiersma, and Jurs, 1998; and Howell, 2002).

In terms of the issue identifying possible outside values, all five textbooks covered the

topic of outliers for a single distribution. And in two of these texts (Abrami, Cholmsky, and Gordon, 2001; and Hinkle, Wiersma, and Jurs, 1998) the authors provided a particularly detailed discussion on how to think about outside values. Moreover, in terms of bivariate relationships, three of the five texts included discussions on the possible effect of outliers on the correlation coefficient, and two of these texts provided "rules of thumb" based on the analysis of standardized residuals for identifying possible outliers.

Howell's (2002) text was the most notable in terms of integrating graphical displays throughout the text. For example, Howell included a box-and-whiskers plot and stem-and-leaf display to accompany his one-sample *t*-test example (p. 187) and matched-pair *t*-test example (p. 193). He included a box-and-whisker plot to accompany his one-factor ANOVA example (p. 334). Lastly, he included stem-and-leaf displays to accompany his multiple linear regression example (p. 537).

Summary and Recommendations

What impact has Tukey's writings on EDA had on the content of introductory statistics textbooks in the behavioral sciences? For better or worse, in this study, Tukey's name was most often cited in terms of one or more specific EDA techniques--most typically, the stem-and-leaf display, and, to a lesser extent, the box-and-whiskers plot. EDA philosophy, by contrast, was not covered in the vast majority of these textbooks. Only three textbooks had a chapter devoted to EDA, and none of the remaining texts even had a section devoted to this topic. In terms of integrating EDA principles throughout the text, only Howell (2002) included stem-and-leaf displays and box-and-whisker plots as part of his illustrations of various significance tests.

Why isn't EDA already routinely integrated into statistics textbooks in the behavioral sciences? Although there is no empirical evidence to answer this question, several explanations

seem plausible. First, some statistics textbook authors might not be familiar with EDA, and therefore might not see the value in it. Along these same lines, they might think EDA is "fudging" the data. Second, some statistics textbook authors might be driven by market demand to write a one-semester statistics textbooks that focuses mainly on "old standard" statistical significance tests. In fact, there probably is not enough time in a typical one-semester course to cover EDA principles and procedures *and* to cover advanced statistical CDA procedures such as higher-order ANOVA, so some trade-offs would need to be made. But in terms of modeling "best practices" in data analysis, it makes more sense to include EDA in an introductory class, and save advanced CDA procedures for more advanced classes.

Final Recommendations

1. *Introductory statistics classes should have a unit devoted to EDA.* The EDA unit should appear at the beginning of a course, since EDA typically precedes CDA, and address the basic philosophy and techniques of EDA.

2. *In discussing hypothesis generation and model-building with EDA, the issue of cross-validation must also be addressed.* The topic of cross-validation was not addressed in any of the 20 textbooks considered here, even those textbooks that specifically discussed EDA. This is problematic. Although EDA can be a powerful means of developing hypotheses and building models, CDA should not be conducted on the same data set that was used for model building, because doing so will lead to an inflated Type I error rate. To actually test hypotheses based on discoveries from EDA, a second data set is needed. This two-stage process--known as cross-validation--requires relatively large data sets, and needs to be considered at the design-stage of a study.

3. *Journal editors should clearly convey the message that it is not only acceptable to*

explore data, but desirable. As Behrens (1997) stated, "... all published and initial work should be explored. The field would greatly benefit if all published reports included the statement 'we examined the data in detail and found the patterns underlying the summary statistics were not obviously pathological'" (p. 154).

For too long, the process of data analysis in psychological research has been viewed strictly in terms of a confirmatory model. Hopefully, the findings of this study will serve as a springboard for future discussions about the value of EDA in the behavioral sciences as well as the way in which we should be training students to think about the data analytic process.

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Table 1

Frequency of Various EDA-Related Indicators (N = 20 textbooks)

Number of texts in which ...	Number
<u>EDA Philosophy</u>	
one or more EDA publications by Tukey or his colleagues are cited as a reference:	7
the philosophy of EDA is covered:	5
an entire chapter is devoted to EDA:	3
the term "confirmatory data analysis" is used:	0
<u>EDA Techniques</u>-Graphs	
a stem-and-leaf display for one or more groups is presented:	15
the origin of the stem-and-leaf display is attributed to Tukey:	10
a box-and-whiskers plot for one or more groups is presented:	9
a box-and-whiskers with "outside values" plotted outside the "whiskers" is presented:	7
the origin of the box plot is attributed to Tukey:	7
a graphical display for the data associated with an illustration of a *t*-test is presented:	1
students are asked to construct a graph for at least one end-of-chapter *t*-test assignment	1
<u>EDA Techniques-</u>Outliers	
outliers are mentioned in terms of a single distribution:	12
the possible of effects of outliers on r_{yx} is discussed:	10
Tukey's method for identifying "outside values" is presented:	4
<u>EDA Techniques-</u>Resistant Indicators	
Tukey's five-number summary (min, Q_1, Q_2, Q_3, max) is presented:	4
Tukey's notion of "resistant indicators" is mentioned:	2
<u>EDA Techniques-</u>Smoothing technique	
nonlinear transformations for a single quantitative variable are presented:	3
smoothing techniques for a single quantitative variable is presented:	0
<u>EDA Techniques-</u>Bivariate Procedures	
the "Tukey line" for the relationship between two quantitative variables is presented:	0

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